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### Culturally Inherited Cognitive Activity: Implications for the Rhetoric of Science

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**Title:** Culturally Inherited Cognitive Activity: Implications for the Rhetoric of Science<sup>1</sup>  
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### ***Introduction***

Few constructs rest more securely upon the foundation of rhetorical theory than the syllogism. Introduced by Aristotle in the fourth century BC, the syllogism provided Athenian orators with structural guidance for constructing valid, deductive arguments in the polis (Aristotle, 1991, 40; Aristotle, 1984a; Aristotle, 1984b). Yet this guidance is not without qualification: Often neglected in modern times is the fact that valid conclusions, for Aristotle, were only expected to follow necessarily from the premises when the audience was comprised of men acting in accordance with *orthos logos*, or "right reason" (1984c, 1935-36; 1984d, 1766, 1797, 1798, 1808, 1812, 1819). Also neglected in modern times is the fact that Aristotle thought of "right reason" as a developed ability that "comes to us if growth is allowed to proceed regularly" rather than as an innate aspect of human cognition (1984c, 1939-40). When such growth does proceed regularly, the prudent man, replete with a sort of cultural wisdom and acting in accordance with *orthos logos*, emerges (1984d, 1748). Put more generally, then, the validity of Aristotle's syllogism rests not upon a bedrock of universal logic but upon the intersubjective agreement of the enculturated Athenian citizens of his time.

Furthering the case for culture in the study of cognition is the Russian psychologist Alexander Luria, who, in *The Making of Mind*, noted considerable variation in syllogistic reasoning among the remote villagers of Uzbekistan and Khirgizia. Although the villagers were adept at reasoning from practical experience, Luria concluded that they were unable to infer syllogistically for the following reasons:

The first was a mistrust of initial premises that did not arise out of their personal experience. This made it impossible for them to use such premises as a point of departure. Second, they failed to accept such premises as universal. Rather, they treated them as a particular statement reflecting a particular phenomenon. Third, as a result of these two factors, the syllogisms disintegrated into three isolated, particular propositions with no unified logic, and they had no way in which to channel thought into the system. . . . Although our nonliterate peasant groups could use logical relations objectively if they could rely on their own experience, *we can conclude that they had not acquired the syllogism as a device for making logical inferences.* (1979, 79-80; my emphasis)

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<sup>1</sup> The development of this paper is sufficiently strange to warrant a brief explanation: As I finished my Gentnerian analysis of Hantaro Nagaoka's Saturnian theory of atomic structure in the spring of 1998, I was left with the unsettling feeling that I had somehow failed to articulate the aspects of Gentner's theory that made it so uniquely appealing. Yet I published the analysis nonetheless (Little, 2000). Only after attending Charles Bazerman's sociocultural learning theory course two years later did I begin to understand those unique aspects of Gentner's theory in the light of cultural variation, and I published this realization shortly thereafter (Little, forthcoming). This present paper, then, only represents my attempt to (1) synthesize those fragmented thoughts and findings from my previously published work, and (2) re-present my thinking and analysis in a more coherent and complete fashion today.

A comparison of this work to that of Aristotle's reveals a remarkable difference in cultural underpinnings: Whereas "right reason" ensured a tacit fluency in syllogistic reasoning among the enculturated Athenian citizens of Aristotle's time, the developmental histories of Luria's peasants provided them with a functional set of literate practices in which the syllogism was nowhere to be found. Cultural inheritance, then, seems to account best for these sorts of differences in reasoning practices as well as for the highly stabilized presence of the syllogism in Western cognitive activity, both ontogenetically and phylogenetically.

Today, we seem to overlook the importance of cultural variation in our own work and, instead, project the latent assumption that fundamental cognitive processes, such as syllogistic and analogical reasoning, are universal properties of human cognition. In this paper, I attempt to address this issue of cultural variation by sketching a sociocultural path for future studies of analogy. I begin by reviewing a sample of the rhetoric of science literature to illustrate our present tendency to treat analogy as a universal cognitive device. Afterward, I draw briefly from social scientific research that shows notable cases of cultural variation in analogical reasoning, before introducing Lev Vygotsky's concept of internalization and Dedre Gentner's structure mapping theory of analogy as fruitful theoretical and methodological means by which to examine more effectively, and with improved cultural sensitivity, the role of analogical reasoning in science. Finally, I offer my own Gentnerian analysis of the role of analogical reasoning in Hantaro Nagaoka's Saturnian theory of atomic structure as an example of the sort of work enabled by Gentner's theory.

### ***Treating Analogy as a Universal Cognitive Device***

That rhetoricians of science treat analogy as a universal cognitive device owes at least in part to the macroscopic conception of analogy inherent in their approach (Little, 2000, 69). By treating analogy as an ossified device that operates in a collective way, rhetoricians tend to focus their attention solely on the varying rhetorical *effects* of analogy, which eclipses from critical examination the possibility of cultural variation in the *interpretation* of the analogy itself. In short, the macroscopic conception of analogy lacks the "resolving power" necessary to identify differences that exist across cultures or within cultures over time.

To illustrate this point, consider the work of Alan Gross: "[A]nalogy," he explains, "has had a long history in the sciences. An important device in Aristotle's scientific writing, it is still very much in use today: the concept of the genetic code is a scientific analogy" (1996, 22). Gross then examines the function of analogy in the political oration of Franklin Delano Roosevelt, the scholarly debate between Karl Popper and Thomas Kuhn, and the scientific theorizing of Francis Crick and company to show that analogy functions differently in each domain, representing different disciplinary communication strategies (1996, 21-32). However, nowhere in the analysis was the analogy itself dissected and examined; what is more, insofar as Gross remains indebted to a macroscopic conception of analogy, he is unable to do otherwise. Because his conception of analogy lacks a sufficient level of methodological granularity, he is virtually forced to tacitly assume that analogy is a universal device, perhaps *used* differently in different contexts, but interpretively stable over culture and time.

Indeed, analogy has had a long history in the sciences. But how do we know that the analogy of Aristotle's day approximates the analogy of today, that is, that analogy has been interpreted uniformly over the history of science and across the three domains of interest to Gross? In fact,

as rhetoricians of science, we do not, and therein lies the latent assumption of interpretive invariance, or universality.

Similarly, in his work on the *Origin of Species*, John Angus Campbell investigated Darwin's domestic breeder-natural selection analogy insofar as it served Darwin's supposed strategy of portraying natural selection through everyday language. But again, at no time throughout his work (1974; 1975; 1986; 1989; 1995) does Campbell disassemble the cardinal analogy of natural selection and ask what the audience might have construed as logical consequences of the constituent correspondences individually. Without such work, we are left to our imaginations when understanding the set of candidate inferences the analogy was likely to suggest to Darwin's Victorian society, to Darwin's proximate audience, and to Darwin himself, or to detect any variation in analogical inference across these domains.

In neuroscience, the tendency remains the same. Edwin Clark and L. S. Jacyna examine the heuristic role of several analogies within neuroanatomy and neurophysiology in *Nineteenth-Century Origins of Neuroscientific Concepts*. Here, we learn of the paradigm shift effected by the encephalon-spinal cord analogy, which not only interjected the term "ganglion" into cerebrospinal terminology but also recast the brain as a "conglomeration of ganglia" (1987, 31). This set the stage for Franz Gall and Caspar Spurzheim's attempt to unify all vertebrates under the ganglion concept through an analogy between ganglion system growth and plant system growth (1987, 36, 45). Clark and Jacyna also tell the story of Gustav Valentin and Jan Purkyne's "imaginative leap" by analogy to show that ciliary motion, which was known to occur on the external surfaces of invertebrates, also occurs inside vertebrates, particularly on the ventricles of the brain (1987, 66). However, like Gross and Campbell, Clark and Jacyna resist detailed explication: Rather than disassemble the driving analogies in their subject, they approach them macroscopically, which precludes from examination the possibility of cultural variation.

### ***Toward a Culturally Sensitive Approach to Analogy in Science***

If analogical reasoning did not admit of cultural variation with respect to interpretation, then a universal conception of analogy, which the macroscopic approach seems to suggest, would be appropriate, even ideal. However, such is not the case: In Andrew Ortony's anthology *Metaphor and Thought*, for example, Dedre Gentner and Michael Jeziorski acknowledge the sociocultural variation in analogical reasoning through their examination of its dramatic shift in interpretation in 17th-century chemistry:

The alchemists relied heavily on similarity and metaphor in their investigations of the nature of matter; but their use of similarity differed sharply from that of modern scientists. In particular, the alchemists lacked a sense that analogy in the modern sense had any advantage over surface similarity or over metonymic, richly interconnected but unclarified forms of similarity and metaphor. . . . The marked difference in the style of analogizing between the alchemists and later scientists suggests that the uses of analogy and similarity are in part culturally defined. (1993, 475)

Even more pertinent is Gentner's finding that literary communities are more accepting of nonclarified similarity than are scientific communities. Likewise, Shen (in Gentner and Jeziorski, 1993, 476) has argued that the rich, many-to-one mappings of literary metaphor are met with skepticism in modern scientific discourse, where clarified, one-to-one correspondences are preferred.

What, then, can account for the relative stability of analogical interpretation within individual discourse communities (e.g., modern physics or English literature) while simultaneously acknowledging its instability across communities (e.g., physics compared to English literature) and across time (e.g., alchemy compared to modern chemistry)? If rhetoricians of science are to begin to orient themselves toward such cultural contingencies, then attending to these fundamental questions seems the most appropriate place to begin. To do so, I turn to Lev Vygotsky and Dedre Gentner for theoretical and methodological assistance.

### ***Vygotsky's Concept of Internalization***

Vygotsky's concept of internalization is best understood within the context of language development in children. Unlike Jean Piaget, who conceived of language as originating in the individual and proceeding outward toward social interaction, Vygotsky reversed the trajectory of development: "The primary function of speech," Vygotsky explains, "in both children and adults, is communication, social contact. The earliest speech of the child is therefore essentially social" (1986, 34-35). For Vygotsky, language develops in response to social pressures; presumably, children realize their dependence upon the services of their caregivers, and any system of gestures, symbols, or cries that facilitates receipt of those services will do. Over time, children and caregivers negotiate a mutually acceptable system of language, predominantly oral, through which to interact, and it is within this interaction that the origin of socialization lies.

At some later point in the development process, children begin to use their language of social interaction for personal activity; when confronted with a problem, for example, they begin to talk to themselves, that is, they begin to engage in egocentric speech. This form of speech does not merely accompany personal activity; rather, it *directs* it, becoming "an instrument of thought in the proper sense--in seeking and planning the solution of a problem" (1986, 31). Echoing the ontological relativism of Edward Sapir, Vygotsky remarks:

By means of words children single out separate elements, thereby overcoming the natural structure of the sensory field and forming new (artificially introduced and dynamic) structural centers. The child begins to perceive the world not only through his eyes but also through his speech. As a result, the immediacy of "natural" perception is supplanted by a complex mediated process. . . . (1978a, 32)

Still later in the development process, egocentric speech diminishes and ultimately disappears altogether; however, again in stark contrast to Piaget, Vygotsky insists that egocentric speech does not merely atrophy but "goes underground" to form the condensed language of inner speech, which continues throughout adulthood in shaping thought and subsequent action (1986, 33). This entire process of internalization, from social to egocentric to inner speech, is one that Vygotsky does not take lightly:

The greatest change in children's capacity to use language as a problem-solving tool takes place somewhat later in their development, when socialized speech (which has previously been used to address an adult) is *turned inward*. Instead of appealing to the adult, children appeal to themselves; language thus takes on an *intrapersonal function* in addition to its *interpersonal use*. When children develop a method of behavior for guiding themselves that had previously been used in relation to another person, when they organize their own activities according to a social form of behavior, they succeed in applying a social attitude to themselves. The history of the process of *internalization of*

*social speech* is also the history of the socialization of children's practical intellect.  
(1978b, 27)

The implications of the social origins of inner speech are paramount when we consider the relation between language and thought that Vygotsky held. Language, for Vygotsky, is the primary prerequisite for conceptual thought; it is the conceptual quality of the word that mediates our sensory perceptions of the immediate moment to enable a "*generalized* reflection of reality" (1986, 6). This frees us from the immediate moment both visually and temporally. According to Vygotsky, language enables children to reorganize and reconstruct their visual perception, thus "freeing themselves from the given structure of the [visual] field" (1986, 35). He continues:

With the help of the indicative function of words, the child begins to master his attention, creating new structural centers in the perceived situation. As K. Koffka so aptly put it, the child is able to determine for herself the "center of gravity" of her perceptual field.  
(1978a, 36)

Visual perception aside, language also enables children to construct a temporal continuum from past through present to future. This enables the child to "view changes in his immediate situation from the point of view of past activities, and he can act in the present form from the viewpoint of the future" (1978a, 36). Vygotsky continues:

Through verbal formulations of past situations and activities, the child frees himself from the limitations of direct recall; he succeeds in synthesizing the past and present to suit his purposes. The changes that occur in memory are similar to those that occur in the child's perceptual field where centers of gravity are shifted and figure and ground relationship are altered. The child's memory not only makes fragments of the past more available, but also results in a *new method of uniting the elements of past experience with the present*.  
(1978a, 36)

It is through this conceptual reflection of reality, acquired through the internalization of social discourse, that we acquire such cognitive processes as syllogistic and analogical reasoning. What constitutes a valid interpretation of analogy in a given time or place, then, is culturally inherited through the tacit structures of the ambient discourse of that time or place, from infant caregiving through primary, secondary, and advanced schooling. To communicate as infants, we must adhere, to some degree, to the local norms for symbolic activity, which we, in time, turn inward as tools for our own problem-solving activities. Yet the process does not stop there: To communicate as adult members of a particular discourse community, we must adhere, to some degree, to the local norms for symbolic activity as well, which we, in time, turn inward as tools for our own problem-solving activities. And therein lies the sociocultural origins of analogical reasoning, which explains, at least conceptually, the relative stability of analogical interpretation within individual discourse communities while simultaneously acknowledging its instability across communities and across time.

To the extent that rhetoricians of science wish to investigate such variation in interpretation, they are unable to do without incorporating a more socioculturally sensitive theory of analogy that is capable of detecting the nuanced differences in analogical interpretation. To this end, I suggest Dedre Gentner's structure mapping theory of analogy.

### ***Gentner's Structure Mapping Theory of Analogy***

Under the rubric of social science research on analogical reasoning exists a substantial and active body of literature dedicated to the selection process by which correspondences between the base and target domain of an analogy are established, that is, the ways in which analogies are "drawn." This scholarship is unified and catalyzed by a fundamental fact, well known within the field: in every analogy between two domains, each containing  $m$  predicates and  $n$  attributes, lay  $m!n!$  potential correspondences—similarities that could be mapped from the base to the target domain during the process of analogical reasoning. "Thus," explain Holyoak and Thagard (1989, 298), "a typical analogy between analogs with 10 predicates and 5 [attributes] each generates over 400 million possible mappings"—assuming that predicates map only to predicates and attributes only to attributes in a one-to-one fashion. Because analogical reasoning is not nearly as arbitrary as the  $m!n!$  rule predicts, cognitive psychologists assume that a set of constraints must govern this selection process, and it is precisely their attempt to codify these constraints that drives their research.

Gentner's structure mapping theory of analogy represents one of the most prominent theories of analogy in the cognitive psychology literature, one that has enjoyed a considerable amount of attention since its 1983 inception. Aiming in part to "capture . . . the descriptive constraints that characterize the interpretation of analogy and similarity" (Gentner and Jeziorski, 1993, 448, 450), the structure mapping theory sets forth six principles that guide the process of analogical reasoning:

- 1) Structural consistency. Objects are placed in one-to-one correspondence and parallel connectivity in predicates is maintained.
- 2) Relational focus. Relational systems are preserved and object descriptions disregarded.
- 3) Systematicity. Among various relational interpretations, the one with the greatest depth—that is, the greatest degree of common higher-order relational structure—is preferred.
- 4) No extraneous associations. Only commonalities strengthen an analogy. Further relations and associations between the base and target—for example, thematic connections—do not contribute to the analogy.
- 5) No mixed analogies. The relational network to be mapped should be entirely contained within one base domain. When two bases are used, they should each convey a coherent system.
- 6) Analogy is not causation. That two phenomena are analogous does not imply that one causes the other.

The purely syntactic nature of these principles sets Gentner's theory apart from her colleagues' theories. For Gentner, neither the goal state of the individual nor the relative importance of the domain information is pertinent to the mapping process. In other words, Gentner argues that scientists "draw" analogies in accordance with these six principles regardless of audience or purpose.

Gentner's structure mapping theory of analogy is "microscopic" in the sense that it treats analogy not as a fundamental device that operates in a collective way but as a composite of

analogical correspondences in which each correspondence has the potential to operate autonomously. This focus on analogical correspondences rather than on analogy as a whole provides a much improved "resolving power" for rhetorical studies of analogy. It enables a detailed examination of the role of each constituent correspondence in a given scientific context and provides a sufficiently refined technical vocabulary by which to describe the results. To this end, I offer my own analysis of the role of analogical reasoning in Nagaoka's Saturnian theory of atomic structure in the following section.

### ***An Analysis of Nagaoka's Saturnian Theory of Atomic Structure***

The turn of the 20th century arguably represents the most fruitful period in the history of modern physics, and nowhere did these remarkable achievements shed more light than on our understanding of the structure of the atom. By the last half of the nineteenth century, the development of such programs as organic and physical chemistry, the kinetic theory of gases, and modern spectroscopy firmly entrenched the atomic hypothesis within the foundation of modern physical science (Heilbron, 1964, 1). But the cardinal discoveries of the 1890s—X-rays, radioactivity, the Zeeman effect, and the electron—simultaneously demanded that our conception of the atom be fundamentally revised. Between 1897, when J. J. Thomson discovered the electron, and 1913, when Niels Bohr advanced the first quantum-mechanical theory of atomic structure, the atom was shown to be not simply the "hard massy sphere" of Newton's day (*atomos* in the Greek sense) but a dynamic system of still smaller positively and negatively charged particles describable only through a bold synthesis of classical and quantum mechanics (Conn and Turner, 1965, 16; French and Taylor, 1978, 27).

To account successfully for visible natural phenomena in terms of an invisible atomic structure was an exercise not only in mathematical rigor but also in creative thinking, for in the early 1900s neither the nature of positive electricity nor the mechanism responsible for spectral emissions was known, the cause of atomic weight was a still mystery, and the intensity of the line spectrum had yet to be studied (Yagi, 1964, 29); spectroscopic data, however precise, proved inconclusive for questions of the size of the atom, of radiation collapse, and of the motion of the electron (Heilbron, 1964, 112). Thus, the remarkable achievements of the recent past created little constraint over early theory construction, permitting physicists an unusually wide variety of candidate hypotheses (and personal predilections) from which to attempt their solutions to the question of atomic structure.

Such was the setting for Hantaro Nagaoka on December 5, 1903, when he unveiled his Saturnian theory of atomic structure before the Physico-Mathematical Society of Tokyo. In essence, Nagaoka drew via analogy from Maxwell's Adam's Prize-winning essay, "On the Stability of the Motion of Saturn's Rings," to propose an atomic system that accounted for alpha and beta radioactivity and "whose small oscillations accord qualitatively with the regularity observed in the spectra of different elements and by which the influence of the magnetic field on band- and line-spectra is easily explicable" (1904, 445).

Nagaoka acknowledged his debt to Maxwell in his first paper on atomic structure, "Kinetics of a System of Particles Illustrating the Line and Band Spectrum and the Phenomena of Radioactivity":

The system, which I am going to discuss, consists of a large number of particles of equal mass arranged in a circle at equal angular intervals and repelling each other with forces



inversely proportional to the square of distance; at the centre of the circle, place a particle of large mass attracting the other particles according to the same law of force. If these repelling particles be revolving with nearly the same velocity about the attracting centre, the system will generally remain stable, for small disturbances, provided the attracting force be sufficiently great. The system differs from the Saturnian system considered by Maxwell in having repelling particles instead of attracting satellites. (Nagaoka, 1904, 445)

By reasoning by analogy, Nagaoka superimposed the dynamic system of Saturn and its rings onto the structure of his "ideal atom," creating a "quasi-stable" atomic model containing electrons in dynamic equilibria whose displacement accounted qualitatively for the regularity of spectral emissions. The orthogonal orientation of the displacements about their dynamic equilibria enabled Nagaoka to account for the apparent fact that line spectra and not band spectra are influenced by magnetic fields, a phenomenon known as the Zeeman effect. And the high-velocity, quasi-stable particles provided a straightforward account for alpha and beta radioactivity.

Nagaoka's system differs from Maxwell's "in having repelling particles instead of attracting satellites": Maxwell's is a gravitational system, whereas Nagaoka's is an electrical, though not an electrically neutral, one. Accordingly, Nagaoka replaced the gravitational force of Maxwell's system with its electrical analog, Coulomb force, and neglected the magnetic component (Schott, 1904, 437). Charge replaced mass as the salient property of the system, but the mechanisms through which Nagaoka explained atomic spectral emissions, the Zeeman effect, stability, and radioactivity remained intact.

### ***Structural Consistency***

Gentner et al. (1997, 6) define a structurally consistent correspondence as "one that satisfies the [limitations] of *parallel connectivity* and *one-to-one mapping*." Parallel connectivity stipulates that the objects of corresponding predicates must also correspond; that is, they must hold as analogically synonymous throughout any subsequent inferential frameworks. For example, if the base domain predicate BETRAYED (Judas, Jesus) corresponds to the target domain predicate BETRAYED (Claudius, King), then parallel connectivity requires that Judas correspond to Claudius and that Jesus correspond to King (and vice versa). Thus, the phrase "Claudius was the Judas of Denmark" makes sense while the phrase "Claudius was the Jesus of Denmark" does not.

One-to-one mapping adds a further limitation: Not only must objects of corresponding predicates correspond, they must do so exclusively, which is to say, in a more general manner, that each object of a domain must correspond to no more than one object of another domain. An analogy that introduces an inconsistent predicate, such as BETRAYED (Gertrude, King), preserves parallel connectivity but sacrifices one-to-one mapping for now Judas may be mapped to Claudius or Gertrude.

A more widely cited example of this sort of structural inconsistency may be found in the prose of the alchemists. In his *Collection des Anciens Alchimistes Grecs*, Bertholet translates a section of a tenth or eleventh century manuscript written by St. Mark to describe the metaphysical symbolism frequently assigned to the egg: "The egg has been called the seed and its shell the skin; its white and its yellow the flesh, its oily part, the soul, its aqueous, the breath of the air" (qtd. in Gentner and Jeziorski, 1993, 465). When confronted with such

inconsistencies, "alchemists resolved the tension by combining both interpretations into a fused whole" rather than choosing a singular interpretation comprised of one-to-one correspondences, and it is precisely this failure to preserve one-to-one correspondences, according to Gentner and Jeziorski (1993, 465), that sharply differentiates the alchemical norm from the modern scientific norm in terms of legitimate analogical reasoning.

In Nagaoka's case, the Saturnian analogy rests almost exclusively upon two fundamental object correspondences: Saturn to the positive central particle and Saturn's satellites to the negative electrons. These two object correspondences are embedded in virtually every predicate correspondence of Nagaoka's framework, including:

REVOLVE AROUND (satellites, Saturn)

REVOLVE AROUND (electrons, central particle)

DISTANCE (Saturn, satellites)

DISTANCE (central particle, electrons)

ATTRACTS (Saturn, satellites)

ATTRACTS (central particle, electrons)

DISPLACES (external force, satellites)

DISPLACES (external force, electrons)

VARIES INVERSELY PROPORTIONAL [ $D^2$  (Saturn, satellites), ATTRACTS (Saturn, satellites)]

VARIES INVERSELY PROPORTIONAL [ $D^2$  (central particle, electrons), ATTRACTS (central particle, electrons)]

For parallel connectivity to exist in the Saturnian analogy, there must be no mixed matching of objects: At no time in Nagaoka's theory can electrons inherit analogically from Saturn, nor can the central particle inherit from Saturn's satellites (and vice versa). For one-to-one mapping to exist, not only must the central particle and electrons inherit from Saturn and its satellites respectively, they must do so exclusively with no extraneous mappings. For example, Nagaoka's analogy cannot attribute an orbital motion to the central particle (a breach of parallel connectivity), require electrons to take on a positive charge (a breach of parallel connectivity), or map Saturn's gravitational force to more than one object in the atomic domain (a breach of one-to-one mapping).

As one might suspect, the Saturnian analogy breaches neither parallel connectivity nor one-to-one mapping. Structural consistency does exist in Nagaoka's case, for nowhere does he rely upon mixed matches or one-to-multiple mappings in his theory.

He opens his "Kinetics" paper of 1904 by sketching his Saturnian theory of atomic structure, after which he contrasts it to Maxwell's celestial system: "The [Saturnian atomic] system differs from the Saturnian system considered by Maxwell in having repelling particles instead of attracting satellites. The present case will evidently be *approximately* realized if we replace these satellites by negative electrons and the attracting centre by a positively charged particle" (1904, 445; his emphasis). He then maintains these parallel object correspondences throughout the entire framework of his theory. His Larmorian treatment of radiation collapse demonstrates parallel connectivity on the issue of charge; never, for example, is the attractive force between

electrons assigned elsewhere. Moreover, the Saturnian analogy invariably maintains a one-to-one correspondence between gravitational attraction in the celestial domain and electrical attraction in the atomic domain, as demonstrated by Nagaoka's equation for the frequency of transversal oscillations.

Structural consistency is also preserved in Nagaoka's explanation of the Zeeman effect (1904, 450) and of alpha and beta radioactivity (1904, 454), for both accounts necessarily suppose a positively charged central particle surrounded by negatively charged, orbiting electrons. At no time does Nagaoka draw from the Saturnian analogy in a way that breaches parallel connectivity or one-to-one mapping.

### ***Relational Focus and Systematicity***

The two most defining principles of Gentner's structure mapping theory of analogy are its focus on relational correspondences and its emphasis on the level of the systematicity among them. "Relational focus" refers to Gentner's claim that "analogy is characterized by the mapping of relations between objects, rather than attributes of objects, from the base to the target" (1983, 168); hence, the term *structure* mapping. For example, the phrase "Claudius was the Judas of Denmark" implies a relational correspondence between Claudius and Judas involving betrayal:

BETRAYED (Judas, Jesus)

BETRAYED (Claudius, King)

The relationship between Judas and Jesus is the salient property, not the particular attributes of Judas or Jesus, such as hair color or weight. That Christians believe Jesus to be the son of God is entirely irrelevant to the interpretation of the phrase because such attributes, according to Gentner, are discarded under modern norms of analogical reasoning.

Within the realm of relational correspondences, systematicity further limits the mapping process by proposing that those correspondences that belong to mutually interconnected relationships are more likely to be imported than isolated ones. "Thus," explain Gentner et al. (1997, 6), "the probability that an individual match will be included in the final interpretation of a comparison is greater if it is connected by higher order relations to a common system of predicates."

Nagaoka's use of the Saturnian analogy affirms Gentner's principle of relational focus, for he draws only from correspondences of a relational nature to corroborate his view of the atom, most notably:

REVOLVE AROUND (satellites, Saturn)

DISTANCE (Saturn, satellites)

ATTRACTS (Saturn, satellites)

DISPLACES (external force, satellites)

VARIES INVERSELY PROPORTIONAL [ $D^2$  (Saturn, satellites), ATTRACTS (Saturn, satellites)]

Object attributes from the celestial domain, such as YELLOW (Saturn), HOT (Saturn), PLANET (Saturn), SPHERICAL (Saturn), or HARD (satellites), play no role in Nagaoka's theory. One object attribute, CHARGED (electron), does present a significant obstacle for

Nagaoka in terms of radiation collapse, but it is entirely a feature of the atomic domain and not imported from the celestial domain during Nagaoka's interpretation of the Saturnian analogy. Indeed, relations do have priority over object attributes in Nagaoka's use of the Saturnian analogy.

Gentner's notion of systematicity plausibly explains why relational correspondences such as DISTANCE (Saturn, satellites) and ATTRACTS (Saturn, satellites) were mapped to the atomic domain while other relational correspondences such as HOTTER THAN (Saturn, satellites) and BRIGHTER THAN (Saturn, satellites) were not. For Gentner, DISTANCE and ATTRACTS belong to a system of coherent, mutually constraining relationships that imbues them with a higher probability of mapping: DISTANCE (Saturn, satellites) and ATTRACTS (Saturn, satellites) are fundamentally interconnected by the law of gravitational attraction operating in the celestial domain. Neither HOTTER THAN (Saturn, satellites) nor BRIGHTER THAN (Saturn, satellites) operate within such a higher order relation; consequently, they are less likely to be imported by an analogy.

Higher-order relations are also effected by higher-order predicates, such as CAUSE, which provide their subordinate predicates with a higher level of systematicity and therefore a higher probability of mapping. In Nagaoka's case, the Saturnian analogy imports to the target domain two correspondences (among others), ATTRACTS (central particle, electron) and REVOLVE AROUND (electrons, central particle), between which exists a higher-order causal relationship:

CAUSE [ATTRACTS (central particle, electrons), REVOLVE AROUND (electrons, central particle)]

For Gentner, this relationship increases the level of coherency and systematicity between the two correspondences (in the same way that the law of gravitation interconnects the DISTANCE and ATTRACTS correspondences), explaining, in part, why the two correspondences are mapped preferentially by Nagaoka over similar relational correspondences.

At no time does Nagaoka draw from the Saturnian analogy in a way that breaches Gentner's relational focus and systematicity principles.

### *No Extraneous Associations*

Another feature of modern analogical reasoning, according to Gentner and Jeziorski (1993, 450), is its disregard for extraneous associations. Only commonalities between the target and base lend credence to the strength of an analogy. For example, that the sun and planets are composed of atoms does not strengthen Rutherford's solar system model of the atom, for thematic associations are irrelevant in modern analogical reasoning.

Nagaoka's use of the Saturnian analogy supports Gentner and Jeziorski's claim, for nowhere does he draw from extraneous Saturnian associations. In the opening of his paper, he introduces the Saturnian model as a tenable theory of atomic structure:

The system, which I am going to discuss, consists of a large number of particles of equal mass arranged in a circle at equal angular intervals and repelling each other with forces inversely proportional to the square of distance; at the centre of the circle, place a particle of large mass attracting the other particles according to the same law of force. If these repelling particles be revolving with nearly the same velocity about the attracting centre,

the system will generally remain stable, for small disturbances, provided the attracting force be sufficiently great. (1904, 445)

Afterwards, to preclude his audience from potentially mapping ATTRACT (satellites, satellites) from the celestial to the atomic domain, Nagaoka highlights the salient difference between his and Maxwell's system: "The system differs from the Saturnian system considered by Maxwell in having repelling particles instead of attracting satellites" (1904, 445). He then proceeds to develop his theory using only the commonalities that lie therein. For example, his mathematical approach to the equations of motion for wave disturbances comes directly from Maxwell, involving, at most, the DISPLACES correspondence of the Saturnian analogy.

Were the setting for Nagaoka's theory that of medieval times, the notion that Saturn is the "ruler of life," combined with the belief that all life is composed of atoms, would have lent substantial credence to a Saturnian view of atomic theory (Cavendish, 1967, 27). But it is precisely this sort of extraneous association that is missing from Nagaoka's theory, which places it in accordance with the modern norm of analogical reasoning as described by Gentner.

### ***No Mixed Analogies***

Not only did Nagaoka refrain from drawing from extraneous Saturnian associations, he also refrained from drawing analogies from any base domain other than the Saturnian celestial system. This satisfies Gentner's fifth principle of modern analogical reasoning, which stipulates that the "relational network to be mapped should be entirely contained within one base domain. When two bases are used, they should each convey a coherent system" (Gentner and Jeziorski, 1993, 450). "In inferential reasoning," explain Gentner and Jeziorski (1993, 450), "[scientists] prefer that the relational system mapped onto a target be drawn from a single base domain".

For Nagaoka, the single base domain was that which Maxwell created in his 1856 essay on the rings of Saturn, and the entirety of Nagaoka's base domain from which he draws analogically lies therein.

### ***Analogy Is Not Causation***

"That two phenomena are analogous," write Gentner and Jeziorski, "does not imply that one causes the other" (1993, 450). This last principle of Gentner's theory of analogy is a rather unremarkable claim: although instances of causation may exist in the base domain and be legitimately imported to the target domain, instances of causation may not span the base and target domain in modern analogical reasoning.

Although causal relations do operate within his base domain and increase the probability of mapping for certain correspondences, at no time does Nagaoka imply a causal relation from the celestial to the atomic domain. For Nagaoka, in stark contrast to his alchemical ancestors, analogy is not causation.

### ***Implications for Rhetoric of Science***

A question still remains: What are the implications for rhetoric of science? In this section, I take advantage of the "microscopic" nature of Gentner's theory and do something that no rhetorician has done: I examine the varying levels of constraint imposed upon Nagaoka by the individual correspondence that constitute the analogy. I begin with the most constraining

correspondence and proceed to the least constraining to show that the Saturnian analogy as a whole did not influence Nagaoka in any collective way. Instead, the individual correspondences constrained Nagaoka to varying degrees on different issues, including nuclear compatibility, the nature of electricity, radiation collapse, spectral phenomena, and alpha and beta radioactivity, functioning sometimes as an asset to his argument and other times as a serious liability.

### **The Strong Constraint of REVOLVE AROUND**

Of all of the correspondences mapped in the Saturnian analogy, REVOLVE AROUND (electrons, central particle) rests most firmly at the foundation of Nagaoka's theory of atomic structure. Once imported to the atomic domain, this predicate requires a spatial scaffolding that strongly constrained Nagaoka in three ways: It required him to posit the existence of electrons, of a central particle, and of a particular spatial relationship between them, namely that the former revolve around the latter in dynamic equilibria.

That the REVOLVE AROUND correspondence constrained Nagaoka by requiring him to posit the existence of the electron was a trivial concern, for not only had J. J. Thomson already discovered the electron, he had also shown it to be a constituent of all matter and therefore indigenous to all atoms. In this case, although the correspondence strongly constrained Nagaoka, it did so to an unremarkable end: the reaffirmation of the only tenable position any scientist could have taken at the time.

That the REVOLVE AROUND correspondence constrained Nagaoka by requiring him to posit the existence of a central particle, however, sharply separated him from his colleagues on two crucial issues: one that would become known as nuclear compatibility, the other having to do with the nature of electricity. Until Rutherford's 1911 discovery of the nucleus, a wide variety of competing structural hypotheses (in addition to Nagaoka's) abounded, including those advanced by Thomson, Jeans, Rayleigh, and Schott. To account for electrical stability, each scientist introduced a unique conception of positive charge to counterbalance the negative charge of electrons. But none chose to envision the positive charge in the form of a central particle.

None except Nagaoka. But for him, it was not a matter of "choice," and this is a point about agency worth making: Whereas the others enjoyed more creative freedom in formulating their conceptions of positive charge, Nagaoka was constrained by the REVOLVE AROUND correspondence to acknowledge a central particle and consequently to place the positive charge therein. It was not that the correspondence suggested to Nagaoka a central particle approach; rather, it required it. Accordingly, in 1904 the Japanese physicist stood as the sole public exponent of a central particle theory of atomic structure, providing the only theory of the time compatible with the discovery of the nucleus in 1911. Thus, Nagaoka's subscription to the Saturnian analogy constrained him in a noteworthy way: it placed him in opposition to Thomson, Jeans, Rayleigh, and Schott on what would become known as the issue of nuclear compatibility.

Not only did the REVOLVE AROUND correspondence constrain Nagaoka to a nuclear compatible theory of atomic structure, it also constrained him to a material interpretation of electricity. Like Saturn and its satellites, the correspondence requires the constituents of the atom to be viewed as separate, rigid bodies influenced by forces acting at a distance. Because Thomson had long since shown the electron to possess the negative charge, Nagaoka quite naturally ascribed to the central particle the positive charge, which in turn implied that not only negative but also positive electricity is corpuscular in nature and fundamental to atomic

processes. Again, it was not that the correspondence suggested a material interpretation of electricity; rather, it required it: while maintaining his subscription to the Saturnian analogy, Nagaoka could not have argued otherwise. Again, Nagaoka found himself in opposition to Thomson, who had hoped to explain the positive charge as a manifestation of interactions among negative charges, leaving the electron as the sole fundamental unit of electricity.

Moreover, the material interpretation required by the correspondence precluded the notion of point-mass particles and therefore denies the idea of interpenetrability of electricity. (For how could one imagine material bodies—celestial or atomic—passing through one another with ease?) For Nagaoka, this was a fortunate constraint. Unlike Thomson, in whose atomic model electrons float freely within a sphere of positive electricity, Nagaoka had rejected the notion of interpenetrability of positive and negative electricity on pre-theoretical grounds (Yagi, 1967, 23; Yagi, 1972, 87): "It is difficult to imagine that electrons move so freely in a positively charged sphere of the atom as if each electron were a geometrical point" (Yagi, 1964, 33). Thus, at a time when empirical data on the nature of electricity proved inconclusive and physicists turned to other means of support, the constraint effected by the Saturnian analogy served as an asset to Nagaoka: it enabled him to argue from analogy as a means by which to support his *a priori* view of electricity in the absence of experimental evidence.

That the REVOLVE AROUND correspondence requires electrons to orbit the central particle in dynamic equilibrium served as one of the most troublesome constraints of the Saturnian analogy, for it forced Nagaoka to confront the inevitable collapse of his Saturnian atom from perpetual loss of energy, a phenomenon known as radiation collapse. This explains in part why no one but Nagaoka chose to adopt a central particle theory of atomic structure before 1911.

Radiation collapse follows from the REVOLVE AROUND correspondence in conjunction with three subordinate correspondences imported by the Saturnian analogy:

DISTANCE (central particle, electron)

ATTRACTS (central particle, electron)

VARIES INVERSELY PROPORTIONAL [ $D^2$  (central particle, electrons), ATTRACTS (central particle, electrons)]

Together, these four correspondences impose a particular order on the atom, analogous to Saturn and its satellites, that required Nagaoka to acknowledge the existence of an attractive force between the central particle and the electrons that varies inversely proportional to the square of their separation distance. In the celestial domain, Maxwell attributed this force to gravitational attraction. But in the atomic domain, where charge replaces mass as the salient property of the particles, Nagaoka predictably accounted for the attractive force by way of electrical attraction. (In his theory, Nagaoka neglected magnetic forces as well as the mutual repulsion among electrons.)

Such a system would be stable (and is indeed stable in the celestial domain), if it were not for one attribute of the electron, well known by 1904:

### ***CHARGED (electron)***

Unlike the satellites of Saturn, the electron possesses a charge, which, in conjunction with the four imported correspondences above, requires that it perpetually radiate energy. Given the

backdrop of classical physics, the electrons would eventually spiral inward, collapsing the atom upon itself until it disintegrated.

Owing to his subscription to the Saturnian analogy, Nagaoka was unable to ignore this debilitating problem: He attempted a solution by drawing from the 1897 work of Larmor, who argued that the radiation loss of an unexcited atom would be negligible if the system were harmonized in such a way that the mean value of the accelerations of the electrons remained at zero. Accordingly, Nagaoka set himself to the task of showing that his Saturnian system is harmonized in such a fashion, which hinges on the point that  $2U-V$  assumes oscillating values about zero, where  $U$  is the total energy of the system and  $V$  is the potential energy. He concluded with haste and in a rather circular fashion:

Thus  $2U-V$  will assume oscillating values, when  $r_k$  and  $r_{kl}$  are subject to small disturbances, provided the quantities  $e$ ,  $E$ , and  $w_k y_k$  and the mean values of  $r_k$  and  $r_{kl}$  are such that  $2U-V$  assumes oscillating values, sometimes exceeding and sometimes falling short of zero. (1904, 446)

Apparently, Nagaoka's solution was to his satisfaction—but to his satisfaction alone. That  $2U-V$  assumes oscillating values does not entail the permanent stability of the atom. Moreover, his argument does not hold for the common case of one electron. Thus, his Larmorian treatment was seen as an unsuccessful solution, and the radiation collapse problem continued to plague his Saturnian atom for the remainder of its life. However, Nagaoka was not hampered as much as one might think, perhaps because his primary purpose, as the opening of his "Kinetics" paper states, was to provide a qualitative account of spectral phenomena and a mechanical analogy of radioactivity, two areas in which the constraints of the Saturnian analogy served him well.

### ***The Weak Constraint of DISPLACES***

The Saturnian analogy also served a more traditional role as a heuristic device for Nagaoka, suggesting to him potential avenues for fruitful inquiry into the innerworkings of the atom. It is in this capacity of "weaker" constraint, where the balance of agency lay in his corner, that Nagaoka found it most useful, for it provided him with a qualitative account of spectral emissions as well as a convenient means by which to account for the Zeeman effect and alpha and beta radioactivity.

The Saturnian analogy served in this capacity through the DISPLACES correspondence set, which is a composite of three related correspondences (Maxwell, 1983, 93):

DISPLACES RADIALLY (external force, electron)

DISPLACES ANGULARLY (external force, electron)

DISPLACES NORMALLY (external force, electron)

It was from the heuristic value of DISPLACES NORMALLY and DISPLACES ANGULARLY that Nagaoka found a qualitative account for band and line spectra respectively, and from the relative spatial relationship between the correspondences that he found a geometrical account for the Zeeman effect.

Once imported to the atomic domain, the correspondence set defines the manner in which an electron may be displaced from dynamic equilibrium when influenced by an external force. In doing so, the correspondence set imports to the atomic domain three degrees of freedom for



electronic motion. (If this seems a trivial point, recall that there were several mechanical analogies of the era that imported different degrees of freedom to their respective domains. Max Planck's conception of a perfect radiator in terms of single harmonic oscillators is a good example of an analogy that imports one degree of freedom to the atomic domain.) Because electronic motion was believed to be the source of spectral phenomena, Nagaoka saw each degree of freedom (radial, angular, and normal) as a potential mechanical explanation for such phenomena. Accordingly, he framed his questions of atomic spectroscopy in terms of sets of equations of electronic motion in the radial, angular, and normal directions and attempted to deduce from them a spectroscopic law, such as Balmer's or Deslandres's, grounded in empirical backing of three decades of research.

It would be misleading to claim that the DISPLACES correspondence set required Nagaoka to search for a mechanical explanation of spectral emissions within the three degrees of freedom it set forth, for unlike the REVOLVE AROUND correspondence, which required Nagaoka to posit the existence of the central particle, the DISPLACES correspondence set simply suggested three potential sources of explanation for spectral phenomena. It did not require that he pursue them.

Nevertheless, Nagaoka chose to follow the path sketched by the DISPLACES correspondence set by investigating the spectral implications of radial, angular, and normal displacements of electrons about their dynamic equilibria in search of a qualitative account for spectral phenomena. Radial displacement had little to offer in the way of spectroscopic implications. But from the equation of motion of normal displacement, Nagaoka deduced the frequency of transversal electronic oscillation, the spectroscopic significance of which he immediately recognized:

For small values of  $h$ ,  $n'$  lie very near each other, but as  $h$  increases, the interval gradually becomes larger and ultimately reaches a maximum. The interval between successive frequencies decreases as  $h$  is increased. Constructing the frequency lines as functions of  $h$ , we find a close resemblance with the band-spectrum. . . . In fact, the above equation is but an extension of Deslandres' empirical formula in a slightly altered form. . . . (1904, 449; my emphasis).

In other words, by supposing a sufficiently large number of electrons in a ring, Nagaoka realized that his frequency equation for normal oscillation produced a graph that accorded qualitatively with the wealth of band spectra evidence amassed. Moreover, by adding the lemma  $h = h_o - h'$ , where  $h_o$  represents the spectral line at the edge, the equation may be rewritten as "one of the empirical formulae used by Kayser and Runge in the discussion of the cyanogen band" (Nagaoka 1904, 450).

Similarly, from the angular equation of motion, Nagaoka deduced the equation for angular frequency displacement of a particle around an attracting center, and again found promising spectroscopic implications:

The frequency increases as  $h$  is increased, and the nature of the series shows that the spectral lines corresponding to these vibrations will gradually crowd together when  $h$  is large. *The qualitative coincidence of the above result with the line-spectrum is at once evident, if  $h$  be not small.* (1904, 451; my emphasis)

Nagaoka interpreted these findings as more than coincidental; they represented tangible evidence for the veracity of his Saturnian theory of atomic structure, at least insofar as the theory

was able to account qualitatively for spectral emissions. Accordingly, in the Saturnian theory of atomic structure, displacement of electrons about their dynamic equilibria accounts for spectral emissions, with displacements parallel to the plane of revolution (in the angular direction) responsible for line spectra and those normal to the plane responsible for band spectra.

That the normal and angular displacements are perpendicular to one another served as a geometrical convenience for Nagaoka, who utilized this spatial relationship to explain "that the Zeeman effect is only peculiar to the line-spectrum, while the band-spectrum is not affected by the magnetic force" (1904, 452). With the introduction of a magnetic field perpendicular to the plane of revolution, Nagaoka argued, comes a force that displaces the electrons radially—parallel to the plane of revolution; according to his equations of motion, these displacement waves propagate around the path of equilibrium at different velocities and are "circularly polarized in opposite sense" (1904, 452), which enabled him to account theoretically for two widely-known effects of a magnetic field on a spectral line: doublets and opposite polarity. Moreover, "[t]he magnetic field perpendicular to the plane of the orbit does not affect the transverse vibrators [perpendicular to the plane]," which corresponds with the experimental fact that band spectra are immune to magnetic influence (1904, 452).

If a magnetic field is introduced parallel to the plane of revolution, then the force responsible for displacing an electron from its dynamic equilibrium is perpendicular to the plane of revolution and, vital to Nagaoka's argument, harmonic (1904, 452). Although the equation may take on an infinite number of individual values oscillating with a finite range, their net effect (mean value) is zero. Therefore, the introduction of a magnetic field parallel to the plane of revolution produces "no sensible effect" on the period of normal oscillations responsible for band spectra (1904, 452). Thus, the relative spatial orientation of the correspondences suggested to Nagaoka a convenient mechanical means by which to account for the Zeeman effect and consequently enabled him to propose a credible atomic system "whose small oscillations accord qualitatively with the regularity observed in the spectra of different elements and by which the influence of the magnetic field on band- and line-spectra is easily explicable" (1904, 445).

Nagaoka's conception of electronic displacement played a role not only in his account of spectral phenomena but also in his account of radioactivity. Drawing directly on Maxwell's investigation of the mutual displacement of neighboring Saturnian rings, Nagaoka argued that for every spectral series there exists a corresponding ring of electrons, "all of which may or may not lie in the same plane" (1904, 453). Because of the close proximity of these rings, electronic displacement in one ring may propagate through neighboring rings and produce unstable modes of vibration in the atom, a prospect that fueled Schott's harsh criticism of the Saturnian atom in the pages of the *Philosophical Magazine*. However, Nagaoka utilized the "quasi-stability" of the Saturnian atom to mechanically account for alpha and beta radioactivity in terms of dynamically unstable Saturnian atoms and their subsequent dispersal of central particles and accompanying electrons. In particular, he demonstrated mathematically that the more massive the ring, the greater the disturbance (1904, 454). Accordingly, in heavier atoms, electronic displacements may produce situations in which the

motion of the ring will . . . acquire such an amplitude as to break the ring. In this case, the particles will fly away with enormous velocities, and the central particle will participate in the same motion, owing to the law of conservation of the centre of mass. If the particles be supposed to be negative electrons, they will disperse in various directions with great velocities, and the positively charged particle at the centre will also fly off.

Here we have arrived at a mechanical analogy, which explains the production of [alpha] and [beta] rays by the disintegration of the ideal atom. (Nagaoka, 1904, 454)

Thus, Nagaoka attempted to redeem the structural instability housed within the Saturnian analogy by framing it as a plausible mechanical explanation not only of alpha and beta radioactivity but also of the higher occurrence of radioactivity in the heavier elements.

At this point, the strength of constraint between the Saturnian analogy and Nagaoka's account of radioactivity is very weak, very marginal, and that is precisely my point: not that the DISPLACES correspondence set served an immense heuristic role for Nagaoka, constraining him in definable ways as he developed his account of radioactivity, but that it subtly suggested to him a mechanical account of radioactivity based on Maxwell's treatment of the mutual influence of neighboring Saturnian rings.

In summary, the Saturnian analogy did not influence Nagaoka in a collective way. Instead, the constituent correspondences of the analogy constrained Nagaoka to varying degrees on different issues, functioning sometimes as an asset to his argument and other times as a liability. As an asset, the analogy demanded a central particle theory of atomic structure, which positioned Nagaoka (we see in retrospect) as the sole physicist to foreshadow Rutherford's 1911 discovery of the nucleus. In its requirement of a material interpretation of electricity, the analogy enabled Nagaoka to support his *a priori* view of electricity in the absence of experimental evidence. It also suggested three potential sources of explanation for spectral emissions and the Zeeman effect and, finally, provided a straightforward account of alpha and beta radioactivity. As a liability, the analogy entailed the problem of radiation collapse, which, despite Nagaoka's Larmorian solution, persisted as the fatal flaw of the Saturnian theory of atomic structure.

### **Conclusion**

What I am suggesting is that Gentner's six principles of analogical reasoning provide a methodologically rigorous, or contestable, matrix to be used in conjunction with textual analysis as a fruitful means by which to begin to investigate sociocultural variation in analogical reasoning and its subsequent rhetorical effect. No longer confined to discussing how analogy might operate collectively and universally, rhetoricians of science may begin to perceive analogical activity through a methodological lens of improved resolution: through structural consistency, which separates to some degree the traditionally medieval scientific cultures from the traditionally modern; through relational focus, which may or may not admit of cultural variation; through systematicity, which seems to vary with respect to the intellectual maturity of the discipline in question (e.g., early to modern cell biology in terms of increased mathematicization and its effects on appropriate reasoning processes); through extraneous and mixed correspondences; and through causation, which seems to separate to some degree alchemical reasoning practices from what is traditionally considered the modern Western norm in science.

Put another way, I am suggesting an alternative to universal idealizations of cognitive processes, such as syllogistic and analogical reasoning, by way of Vygotsky's and Gentner's theoretical and methodological guidance. This paper is my attempt to explicate and exemplify that alternative.

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